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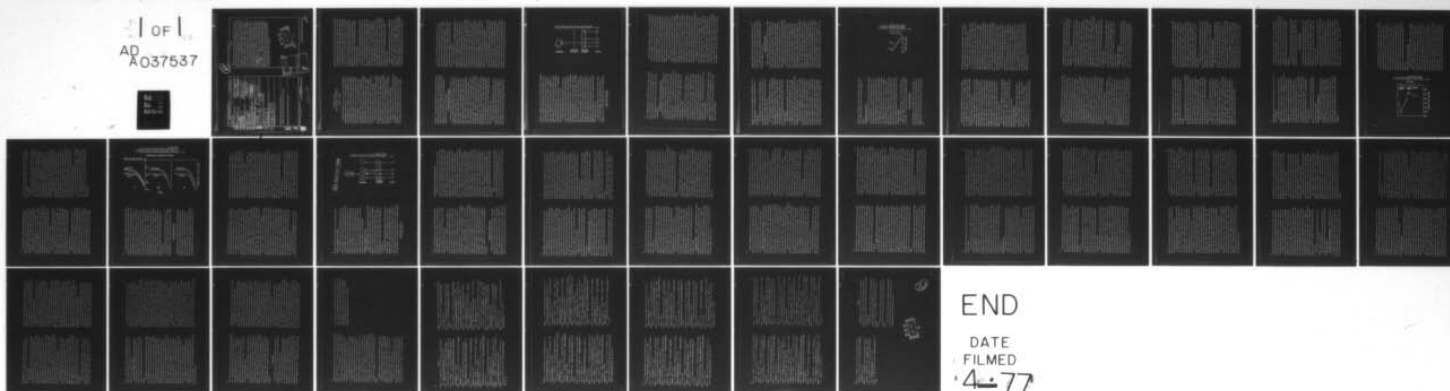   FEB 77   S W KEELE, W T NEILL   N00014-76-C-0344
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Abstract

Control problems of attention theory concern analysis of the source of limitations in processing information, and the mechanisms that control the flow of information from input to output. Early theories of attention suggested a very close link between processes that take time and processes that take attention. But abundant information suggests that at least one time-consuming process, that whereby a stimulus activates familiar associations in memory, demands little or no attention in many instances. Apparently a very wide range of memories within a code and a variety of different codes, such as visual, phonemic, and semantic codes, are activated by the same stimulus. Moreover, more than one stimulus may activate memory at a time. This widespread activation necessitates a limited control process that selects and integrates codes or memories in accordance with goals and task demands. Sometimes the control mechanism may even attenuate one stimulus source prior to memory activation. Such a processing system would appear quite reasonable: All information relevant to a stimulus is usually activated in memory. But it would be quite maladaptive were those activated memories automatically translated into action, for often conflicting actions would result and the action might not coincide with goals of the moment. It is for that reason that a control process selects and integrates the activated memories according to current demands.

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Mechanisms of Attention

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The concept of attention lies at the very core of cognitive psychology; Indeed some people consider attention a primary distinguishing feature from classical behavior theory. According to some classic theories of learning, any conditionable stimulus that reliably precedes a conditionable response by a short amount of time will come to elicit that response. Such theories regard people and animals as passive receivers and transformers of information from the environment. It is now well established even for animals (e.g., Reynolds, 1961), however, that only one of two simultaneous stimuli might be conditioned, implying selection from among the available information. The selected stimulus varies between animals and with context. In general, and not only in conditioning, the nervous systems of animals and people alike are severely limited in processing information. Only some information is perceived, only some is responded to, only some is remembered.

The study of attention is concerned with the nature of these limitations and with the selective processes that deal with them. Where in the sequence of information processes do limitations occur? What options do people have about which information is selected? What happens to non-selected information? What are the costs and benefits of selection? Although many different approaches to the problem of attention exist, the present review concentrates on the analysis of attention in perceptual tasks by humans.

A study by Klein and Posner (1974) vividly illustrates the limited nature of processing as well as some types of mental operations that draw on processing capacity. A target light moved horizontally across an oscilloscope screen, reversing directions at one, three, or five points. The actual reversal points varied on different trials, and after each pattern the subject tried to reproduce the time and positions of the reversals by moving a lever.

In one condition subjects visually observed the pattern before reproducing it. In a second condition they not only observed the pattern but also tracked it by moving the lever to follow the target with a cursor. In the former condition the subject has available only a visual input with which to remember the pattern, but in the latter condition both visual and kinesthetic inputs are available. Which is the easier condition to reproduce? Many people expect the dual code to be better; in fact, people were more accurate when only visual input was available.

The Klein and Posner result appears paradoxical because two inputs are worse than one. What theory could explain the paradox? Two possibilities are: (1) The process of correcting tracking errors requires attention, competing with the attention demands of storing the information in memory; and (2) Attempts to store two codes draw on a limited storage mechanism and result in mutual interference--i.e., only one code can be rehearsed at a time. Both hypotheses appear partly correct. Klein and Posner show that corrections sometimes interfere with reaction time to other signals, implying attention demands of the corrective process in tracking. They also show that when the arm is passively moved rather than actively moved in tracking, memorizing both codes also results in interference even though corrections in tracking are eliminated.

Many people closely identify attention with being able to remember what was attended. Clearly, in view of the Klein and Posner study, such a link should be avoided. Instances exist in which apparently greater investment of attention, as in tracking, actually impairs memory. While memorization may require attention, the converse is not true. The analysis of attention depends on observations of interference between tasks and not only on the recall of

information. As a general working definition, two tasks that interfere with each other are said to require attention. Of course interference for physical reasons, such as the requirement to simultaneously move the finger in opposite directions, is not indicative of attention. Also interference because of peripheral masking is not indicative of attention.

Two Kinds of Processing Limitations

All brain processes take time and this constitutes one limitation on processing. Moreover, the brain exhibits space limitations in terms of the number of things that can be done at once. In the 1950s and early 1960s a widely held view of attention theorized a strong relation between the two types of limitation. This theory, single-channel theory (Welford, 1960), and the closely allied filter theory (Broadbent, 1958) were loosely built around a technical concept of information as developed by Shannon and Weaver (1948). The translation of a signal from a sensory code to a memory or response code was thought to involve a limited capacity channel. Since only one channel existed, the translation of one signal to another code precluded translating another. The greater the information content of the first signal, the longer time it would occupy the channel, and the greater the delay in processing another signal. Under certain versions of the theory, two signals may be processed at the same time. If the information load of both together is less than the capacity available, capacity may be divided between them with no resulting interference. But if the total demand exceeds the available capacity, both signals will suffer.

Evidence for single-channel theory developed on two fronts. On one front, classic experiments by Hick (1952) and Hyman (1953) showed that the reaction time to translate light signals to either key press responses or verbal responses was related to the information processed: reaction time increased linearly with the logarithm of the number of potential stimuli

and responses for a given situation and decreased with the logarithm of stimulus probability when the total number of stimuli was held constant. When errors were made, the information transmitted from signal to response was reduced and the reaction time correspondingly decreased in a linear fashion with the drop in information transmitted. These results from the Hick and Hyman studies all suggested a channel limited to about 150-200 msec per bit of information processed.

However, the time to process each bit of information depends heavily on variables other than the amount of information. Chief among these is S-R compatibility (Fitts & Seeger, 1953): The time to translate a signal to a response depends not only on the number and probabilities of stimuli and responses, but also on the relationship between them. Translation is quicker when stimuli and responses are spatially similar, and sometimes reaction time may hardly increase with information. Leonard (1959) found this to be the case when people respond by pressing down with a finger that is touched; Fitts, Peterson and Wolpe (1963) found it to be the case when people pointed at whatever light was illuminated. In addition, the translation time is greatly reduced with high degrees of practice (Fitts & Seeger, 1953; Mowbray & Rhoades, 1959), again indicating that the time to translate a signal to a response is not strictly limited by the amount of information.

On the second front that attempted to link time and space, it was shown that when two signals were presented about the same time, processing of one or the other or both was slowed. The interference appeared related to the time demands of individual signals. Welford (1959) presented two successive signals, one light followed by another. When the second signal occurred before the first response was emitted, the reaction time to the second signal was delayed. The second signal delay was actually greater than the remaining processing time of the first signal, suggesting that only one signal could

Figure 1. A schematic representation of single-channel or filter theory. Only one signal at a time gains access to the memory system.

STIMULI   SENSORY BUFFERS   FILTER OR SELECTOR   MEMORIES

S_1 S_2 S_3 . . . . . S_n

---

translate to a response at one time; and in addition, monitoring the feedback from the first response further pre-empted the processing channel. Karlin and Kestenbaum (1968) and Smith (1969) increased reaction time to the first signal by increasing the number of stimulus alternatives. Broadbent and Gregory (1967) increased reaction time by decreasing S-R compatibility. Increased reaction times to the first signal were closely matched by further delays in processing the second signal. The results are exactly what would be expected were single-channel theory basically correct: Processing the second signal cannot begin until the first is finished.

Paradigms using simultaneous auditory messages led to a similar conclusion. Cherry (1953) found that when two prose passages were spoken by the same voice and came through the same speaker, selectively repeating one message and ignoring the other was very difficult. If, however, the messages came through separate earphones, the task was relatively easy. When successfully shadowing the message to one ear, subjects were unaware of the semantic nature of the ignored ear. They rarely noticed switches from English to German or to English played backwards. Results of this sort suggested that only one message at a time could be translated from the sensory input to the semantic code. Other variations on the dichotic listening paradigm suggested that the translation process was limited in an information sense. Broadbent (1956), for example, found the disrupting effect of a buzzer on understanding a verbal message to be larger for a two-choice buzzer decision than a one-choice buzzer decision.

A diagram of the theory growing out of these sorts of study is shown in Figure 1, based on Broadbent (1958). When more than one stimulus or message occurs at a time, they are entered in parallel to a sensory buffer.

Insert Figure 1 about here
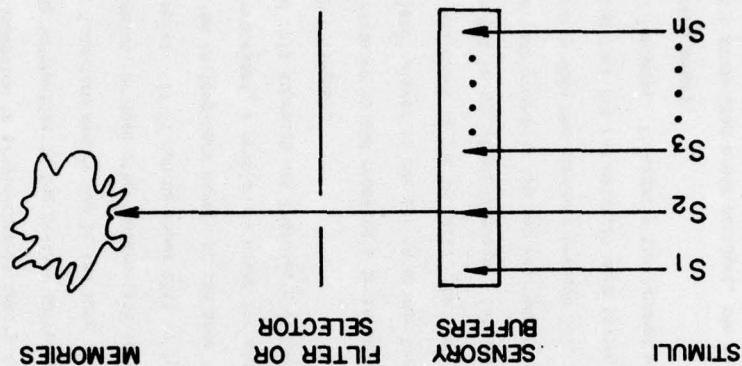
Barring peripheral masking, no interference occurs at this stage. One message is then allowed through a filter while the other message is held in the limited buffer for later processing. The filter prevents overloading a limited capacity mechanism that translates the stimulus to some other code stored in long-term memory.

Illustrative Difficulties for Single-Channel Theory

The central assumption in single-channel theory is a processing limitation in translating information in the sensory buffer to long-term memory. The information in long-term memory may be the name of the stimulus, the meaning of the stimulus, or some other information such as the response to be made to the stimulus. If it can be shown that an ignored stimulus actually activates information in long-term memory at the same time another stimulus is being normally processed, a problem is posed for single-channel theory. One study that used this approach was Treisman's (1964a) shadowing study with French-English bilinguals.

The subjects listened to and repeated a prose passage from Orwell's "England, Your England" played in one ear in either French or English. At the same time, and not known to the subjects, the same passage was played in the opposite ear but in the other language. Initially the two passages were offset in time, but gradually the gap was reduced. When the gap was small, and particularly when the shadowed message led, many of the subjects spontaneously noticed that the two messages were saying the same thing, though different in language. Apparently the ignored message was not entirely blocked from long-term memory.

Since Treisman's study used prose passages, the messages had considerable redundancy; the meanings of early parts of a passage prepare one for a later meaning. This redundancy could be important to the effect and it played a part in Treisman's explanation.

Lewis (1970) avoided redundancy by presenting a list of unrelated words in the ear to be shadowed. The other ear received other words synchronized in onset with the attended items. The reaction time to shadow a word was slightly delayed when the unattended word was a synonym of the simultaneous word in the attended ear. The subjects, however, reported no awareness of the content of the ignored words. Apparently the nonshadowed ear receives semantic analysis and is not entirely blocked prior to long-term memory. Otherwise the semantic nature of the nonshadowed word should have no effect.

Recently Treisman, Squire and Green (1974) replicated some features of Lewis' experiment. They found that the semantic relationship of the non-shadowed to shadowed word had a modest effect on reaction time to shadowed words early in a list, but the effect disappeared by the seventh item shadowed. They suggest that more effective blockage prior to long-term memory occurs as subjects go further into the list. Nevertheless, the results are damaging to single-channel theory in the sense that at least early in the list more than one item may activate long-term memory at one time. Moreover, as Treisman et al. point out, a failure to get the synonymic effect does not necessarily imply blockage. Nevertheless, because of Treisman et al.'s results, a modification by von Wright, Anderson and Steman (1975) becomes more important.

They presented a long list of dichotic words in which a Finnish word meaning "suitable" occurred six times on the attended ear. Two of those occasions were followed by an electric shock. Reappearance of the word produced a galvanic skin response (GSR). Following conditioning, another long list of dichotic word pairs was presented. Subjects shadowed one ear and ignored the other. When the conditioned word appeared in the ignored list, it evoked a GSR change, though not as large as when it occurred in the shadowed ear. More important, when either a synonym or a homonym of the conditioned word appeared in the ignored ear, the change in GSR, though smaller than for

"suitable", was as large in the unattended as in the attended ear. Again it appears the ignored ear is not blocked prior to semantic analysis in long-term memory.[1]

These studies pose a problem for classical single-channel theory. At least some translation of one signal to memory can occur while another is being translated. Theoretical departures from single-channel theory took two major directions to handle such results.

One direction proposed by Treisman (1964a) basically maintained the idea of a limit between sensory and memorial processes. She suggested that an ignored message rather than being perfectly filtered is only attenuated so that some leakage occurs to the memory system. When previous content sensitizes appropriate memory units, or when particular memory units (e.g., one's name) are more permanently sensitized, the leakage is great enough to trigger a response.

The second theoretical answer to problems with single-channel theory was to suggest that more than one signal had unimpaired, parallel access to the memory system and that selectivity, aided by cues such as message location, occurred at the memory level rather than the sensory level. Deutsch and Deutsch (1963) and Norman (1968) were early proponents of this view.

The general question that emerges at this point, therefore, is whether more than one signal has simultaneous and unimpaired access to information about that signal stored in memory. It is quite evident that when two signals must be processed to the stage of separate responses, interference usually occurs; there is a capacity limitation. But is that limitation in the access to information in long-term memory or is it in the mental operations such as rehearsal, response execution, conscious perception, and so on that are applied to information already activated in long-term memory? The answer to this seemingly simple question has been exceedingly elusive.

A number of studies quite convincingly argue that memory retrieval, while time consuming, is non-attentive, and these will be discussed in the next section. Other studies just as convincingly raise problems for the unlimited view. Some of those problems are described and some speculations are made on possible resolutions of the conflict.

Processing Multiple Signals

A general strategy in assessing the source of limitations is to present two signals at about the same time and vary the response requirements. One signal may require a response and the other may not. Both signals may converge on the same response. Both signals may require separate responses. The difficulty of the two stimulus-response mappings may be independently varied. By examining the patterns of interference or facilitation in the different conditions, clues as to the sources of interference may be obtained.

This approach constitutes a micro study of attention that looks in close detail at short lasting processes that normally take less than a second. It differs from the macro study of attention in more complex, continuous tasks. For example, Martin, Marston and Kelly (1973) presented a probe signal during a memory task. Reaction time to the probe indicated large attention demands during all phases of memory, encoding, retention, and retrieval. Each of these phases, however, involves several unanalyzed mental operations. For example, the process they call encoding could involve the activation of the name or meaning of a presented item, conscious recognition, and elaborative rehearsal. All of these are grouped under the heading of encoding. The attention demand at a macro level presumably reflects the mix of micro processes, their rate of occurrence and whether they can be delayed for split seconds while the probe task in handled. Kerr (1973) has surveyed literature looking at macro demands. In this review, the emphasis is on discrete trial settings in which micro processes are examined. These include

studies in which two signals converge on one response, in which two signals
conflict regarding a response, and in which two different responses are
required.

Processing Redundant Information

Consider a situation in which two signals occur simultaneously and both
indicate the same response. According to single-channel theory, reaction
time to the redundant stimulus should be no faster than the fastest of the
two signals when presented alone. Some studies, however, have shown that
the redundant stimulus is actually responded to faster than either component
alone. Morton (1969a) had people sort cards on the basis of either numeral,
1 to 6, numerosity of X marks, ranging from one X to six Xs, or redundant
numerals and numerosity in which the numeral 1 occurred once, 2 twice, 3
three times, etc. The latter case resulted in slightly faster sorting than
either component alone. Moreover, this result was true for individual sub-
jects so that it was not an artifact of averaging over each subject's best
dimension. Biederman and Checkosky (1970) obtained similar results for size
and brightness judgments.

Figure 2 shows data from a study by Ellis and Chase (1971) that make
a similar point. Subjects were shown a set of 1, 2, 3 or 4 letters followed
by a test letter. If the test was a member of the preceding set, subjects

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Insert Figure 2 about here
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were to press one key; if not a member, they were to press another key. On
one-half the negative trials, those in which the test was not a member of
the set, the test letter was smaller than normal. Subjects were told that
whenever they saw a small letter they could immediately press the negative
key.

Figure 2. Reaction time to indicate a stimulus is not
a member of a target set as a function of
target set size and whether the stimulus is
small or normal in size.
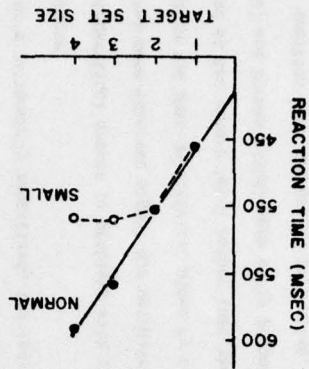
As seen in Figure 2, when the memory set is three or four, subjects are faster when the test item is small as well as a non-member of the memory set. In contrast, when the memory set is only one or two a small test item has no advantage. Similar results were also found when the negative stimulus sometimes had a distinctive color rather than size.

Ellis and Chase's data suggest that people judge size (or color) at the same time they search the memory set. Whichever process is first completed terminates the decision. Since size decisions take longer than searching one or two memory items, small size does not help until the search set consists of three or four items. It could be argued that when memory sets are three or four, subjects try size first and if that fails, they then search the memory set. Such a serial strategy would predict normal size negative responses to take longer than in a control condition in which only normal size letters were used. In fact a control condition with only normal size letters exhibited the same reaction times as normal size letters in the context of small letters on some trials.

The reduction in reaction time to redundant signals is easily explained by parallel access to memory. When a signal occurs memories associated with the stimulus begin to accrue information. If two different signals feed into the same memory, accrual will occur at a faster rate, leading to either reduced reaction time, reduced error, or both.

The Fate of Irrelevant Information

Studies of redundancy suggest that two signals can be processed in parallel when it is advantageous to do so. An even stronger case for automatic parallel access to memory can be made if it is shown that a second signal is processed to memory, even when the result is detrimental.

Suppose two signals occur at the same time and one is relevant to a response and the other irrelevant. When the signals are quite discriminable,

the irrelevant one usually has no discernable effect on reaction time to the relevant one (Morgan & Alluisi, 1967; Well, 1971). At what stage of processing is the analysis of the irrelevant signal blocked?

The Stroop effect, a notable exception to blocking irrelevant information, casts light on the problem. When a person is asked to respond to the color of a stimulus and ignore the form, he has an unusually difficult time doing so when the form spells out a conflicting color word. For example, when the word GREEN is printed in red ink, people are slow in responding red. One interpretation of the Stroop effect, akin to single-channel theory, suggests that words often capture access to the limited processing channel before the color, delaying color processing. This seems unlikely, since irrelevant forms in general do not cause interference, suggesting that form has no privileged access to the translation channel (Archer, 1954; Schroeder, 1976). A second interpretation is that both the color and the word access their names in parallel. When two color names are activated in memory, conflict ensues and additional time or process is required for resolution.

Keele (1972) differentiated between these two interpretations by comparing reaction time to: (1) a colored, meaningless form repeated in a string; (2) colored words that name another color; and (3) colored neutral words. If the single-channel view is correct and words are sometimes processed first, then condition (3) as well as (2) should be more difficult than (1), since in both cases the word would be read before the color could be named. If, however, forms access memory in parallel with color, then only condition (2) should result in interference, since it is the only one that generates conflict. The reaction times to the three conditions respectively were 554, 604, and 559 msec and the error rates were .08, .09 and .07, supporting parallel access.

It could be argued that only the color words have access to the limited channel. This seems unlikely, since to know that a word is or is not a color word requires prior access to memory. Perhaps, however, the recognition units are more sensitive to color words due to the color context. If this were true then on occasions where the word agreed with the color itself (e.g., BLUE written in blue ink), interference should again be observed, since the word would be processed before the color. However, Hintzman, Carre, Eskridge, Owens, Shaff and Sparks (1972) found facilitation, compared to a control with constant meaningless forms, rather than interference on the occasional congruent word and color, again arguing that the two stimuli gain simultaneous access to memory. Clark and Brownell (1975) observed a similar phenomenon with arrows and spatial position. Responding to an up pointing arrow was facilitated when the arrow was high on the display and slowed when low on the display. Moreover, Klein (1964) showed that non-color words having strong color connotations, such as banana or grass, also interfere strongly with color naming. This observation supports the contention that words and colors are analyzed in parallel as opposed to the hypothesis that only color words are sensitized and processed.

A potential interpretive problem with the Stroop studies regards the control condition to which other conditions are compared. The control itself involves colored forms, usually a string of the same nonsense form. It is difficult in fact to present a color control without some form to bear the color. Is it possible that even meaningless forms are processed before beginning color processing, invalidating their use as a control? Some evidence against this view is provided in Keele's study. The neutral word condition involves more different forms than does the constant form control, and yet it takes no longer than does the control. Keele also examined varying nonsense forms and found the same result. When several forms are relevant

for response, variation in form increases reaction time (Beller, 1970). Since variation in form did not influence reaction time in the Stroop setting where form is irrelevant, it is difficult to argue that form was being processed before color was started.

Perhaps more convincing evidence comes from studies such as that by Egeth, Jonides and Wall (1972). In one of the experiments subjects pressed a key whenever any digit was present in an array of distractor letters. No increase in reaction time to the digit occurred with an increase from 0 to 5 in number of distracting letters. Because any digit could occur when in fact a digit was present, it appears very unlikely that digits were being identified by selecting a unique feature not present in letters. Instead it would appear that all the items activate either the concept of letter or digit in memory and if any one activates a digit in memory it is selected. This result suggests, as do studies of the Stroop effect, that irrelevant material is being processed to a memorial stage along with the relevant, but the irrelevant material only causes a decrement in reaction time when it creates confusion about target identity.

Studies on the fate of irrelevant information suggest, therefore, that more than one stimulus has parallel access to memory and that selection occurs after memory activation. Irrelevant information appears not to be completely filtered early in processing, if at all, even when it is deleterious in its effects.

The Problem of Stimulus Integrality

Garner (1974a, b), Kahneman (1973) and Lockhead (1972) suggest that filtering of irrelevant information and redundancy gain depend on the nature of the stimuli. Only integral stimuli yield redundancy gain and produce difficulty in filtering. Integrality can be defined by the experimental results: stimulus dimensions that when combined redundantly result in

redundancy gain and when combined orthogonally result in interference are said to be integral. To avoid circularity, however, integral dimensions can be defined as those that belong to the same object. Thus size and color of the same object are integral but size and color of different objects are separable.

When Garner and Felfoldy (1970) and Felfoldy and Garner (1971) redundantly combined value and chroma of Munsell colors on the same chip and cards with the chips were sorted into piles, sorting time was faster than when both dimensions varied. But when cards with two color chips were sorted with value varying on one chip and chroma on the other, no redundancy gain was observed. The failure of redundancy gain for separated dimensions occurred whether subjects were explicitly told about the redundancy or not. Likewise, when the dimensions were combined orthogonally, variation on the irrelevant dimension interfered with card sorting on the relevant dimension only when both dimensions varied on the same color chips.

Garner and Felfoldy's results could suggest parallel processing only for integral stimuli. For non-integral stimuli, single-channel theory may be correct. Some of the earlier studies of redundancy gain and filtering that implied parallel processing used integral stimuli. In studies of the Stroop effect, word color normally is integral with the word. In the Biederman and Checkosky study and in the Ellis and Chase study, the dimensions are clearly integral. Whether numerosity and numerals in Morton's study are integral is more problematic. The Egeth, Jonides and Wall (1972) study involving search for a digit among letters poses a greater problem for the proposition that only dimensions of an integral stimulus are processed in parallel, for obviously the several forms are not integral.

Other problems also exist for the proposition that only integral dimensions simultaneously contact the memory system. Dyer (1973) presented a color patch on one side of a fixation point and a black color word on the other side of fixation--clearly separated dimensions. Nonetheless, form interfered in making color judgments. Subjects in a study of Morton's (1969b) sorted cards into piles on the basis of number of figures on the card while attempting to ignore auditorially presented numbers. Obviously visual figures and auditory names are not integral, but nevertheless the conflicting numbers slowed card sorting. Moreover, some studies to be described later present evidence for parallel processing of visual and auditory signals.

Stimulus integrality clearly influences redundancy gain and filtering. But if non-integral stimuli are highly related at the memory level, parallel processing is observed. Failure to observe either redundancy gain or interference effects implies only that the stimuli do not interact at either the sensory level or the memory level, not that they are processed serially.

Multiple Activations in Memory by One Stimulus

In Keele's study of the Stroop effect, the colors were responded to by pressing keys. Neutral words have no pre-existing associations with particular keys, and that appears to be the primary reason neutral words do not lead to conflict. When people name the colors rather than press keys, even neutral words lead to a conflicting tendency to verbalize (Klein, 1964). This fact allows the Stroop effect to further index what has been activated in memory. Warren (1972) presented word triads, such as OAK, MAPLE, FIR, to be recalled a few seconds later. Just before recall a colored word was presented, and subjects named the color. If the colored word was a member of the preceding triad, people were slow in naming the color. Moreover, a word associated with the preceding triad (e.g., TREE) also received a

slower response. Reaction time to the color, therefore, indexes prior activation of word meaning.

Conrad (1974) used the Warren technique to assess the activation of ambiguous word meanings in sentence contexts. For example, following the sentence, "The beans are cooking in the pot," she presented either the colored word pot, kettle, marijuana, or a control word. Kettle and marijuana are both meanings of pot, but in the context of the sentence only one meaning is appropriate. Reaction time to name the color of the control word was less than the reaction time for either meaning of the ambiguous word. Furthermore, the appropriate and inappropriate meanings did not differ in their interfering effect. These results suggest that all meanings of words are activated during their presentation, even in a disambiguating context, and that selection of one meaning occurs subsequently. This does not mean that people are aware of both meanings, as only the appropriate meaning may have been selected.

The Conrad result bolsters the earlier conclusion that more than one memory can be activated at a time, though in this instance multiple activation flows from a single stimulus.

Probing Mental Operations with Secondary Tasks

When two signals require separate responses, interference with one or the other normally occurs. But what process generates the interference? The preceding studies imply that the limitation is subsequent to memory retrieval. Thus when two responses are required, a technique is needed that separates in time stimulus contact with names or other memories from later processes dealing with the encoded stimulus. A secondary probe signal can then be inserted to determine whether the ongoing process was demanding of attention.

Posner and Boies (1971) exploited this idea in a matching paradigm. A visual warning signal was followed a half second later by the first of two letters. One second after the first letter a second one appeared, and the subjects were to press one key if the two letters were the same and another key if they were different. An entire second is available for the subject to encode the first item with no necessity during that time for matching or responding.

At various times during the decision process a probe tone was presented and reaction time to the probe was an index of the capacity demand of any ongoing process. Figure 3 shows the probe reaction times. Reaction time

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Insert Figure 3 about here
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to the probe decreases following the warning signal despite the fact that the warning was for the figures, not the probe. More important, probe reaction time remains low up to 300 msec following the first letter. After that point, probe reaction time begins to rise reaching a peak after the second letter. Similar results are found when matching is based on name as well as physical identity.

Why is probe reaction time so low right after the first letter? Perhaps during that time subjects are not encoding the first letter and instead are waiting for the second before encoding either. This possibility can be discounted because when the second letter unexpectedly occurs early, subjects are still faster than when they have simultaneous presentation of the letters. Subjects do take advantage of prior exposure of one letter to encode it. Despite encoding the first letter, there was no interference with the auditory probe. These results suggest, therefore, that the encoding process, in which the signal contacts an internal representation, does not require attention either for name codes or for physical codes.

The probe reaction time is high following the second item to be matched, indicating that either matching or responding or both require capacity. But probe reaction time begins to rise well before the second letter. Why?

One answer, that will be elaborated later, is that while encoding takes no capacity, a limited capacity mechanism can turn to the area of memory activated in anticipation of dealing with the next item. Some evidence for this point comes from a Posner and Klein (1973) experiment. The rise in probe reaction time is more closely related to the time remaining before a second letter than the time after a first letter. When subjects know the second letter is to be delayed, the time at which the upturn in probe reaction time begins is also delayed, beginning about one-half second before the second letter.

Effects of Task Difficulty on Interference

Another method of analyzing which stage, memory retrieval or subsequent operations, generates interference when two signals both require a response is to vary the time required by memory retrieval. Single-channel theory, which posits limited capacity for memory retrieval, would predict that increases in retrieval time of either of two signals would increase total time to process the signals by an amount equal to the increase in retrieval time. Allocatable capacity models make a similar prediction. A pair of tasks may not interfere if they do not use all the capacity; some capacity can be allocated to both tasks. But when interference does occur, it means that available capacity is already used up, and no matter how capacity is allocated, any further increases in retrieval time will increase total processing time for the two signals. Parallel access to memory predicts in contrast that increased retrieval time for one signal may be absorbed during the retrieval time of the other so that total processing time may not be increased by much.

Figure 3. Reaction time to an auditory probe signal as a function of where it occurs during the processing of letters to be matched.
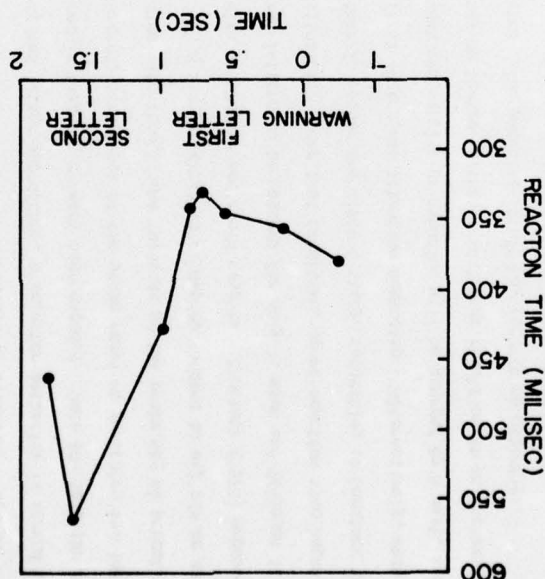
The time to retrieve an appropriate response from memory can be increased by reducing stimulus discriminability, increasing the number of stimuli and responses, and decreasing the compatibility of the stimulus to response mapping. LaBerge (1973) employed the discriminability method.

Subjects were cued to expect either a 1000 Hz tone or an orange light. On most trials the expected signal (e.g., tone) occurred, but on a small number of trials the unexpected signal (e.g., light) occurred. Each signal could be made easy or difficult by requiring detection or discrimination. In the detection condition, catch trials with no signal occasionally occurred. In the discrimination condition the catch trials were a tone of 990 Hz or a yellow light. Catch signals required withholding the response; the other signals required a single button to be pressed.

When the expected stimulus was presented discrimination took 287 msec, which is 83 msec longer than the 204 msec for detection. This result is entirely expected: Discrimination is more difficult than detection. The 83 msec difference is also nearly identical to the value obtained on control blocks of trials with only expected signals. However, when an unexpected stimulus occurred, discrimination averaged 415 msec,[2] only 43 msec longer than 372 msec detection and a sizeable reduction in the difference score from the former value of 83 msec.

LaBerge suggested that when the expected signal failed to occur, a selection mechanism switched to the unexpected one. If discrimination did not start until after switching, then the difference between detection and discrimination should remain at about 83 msec, if not actually larger. The fact that the difference is actually much smaller than 83 msec suggests that discrimination is occurring in parallel with switching of the selector. By the time switching is complete, detection or discrimination is often completed. Elicitation of the response must then wait on the completion

of switching and is not sensitive to the difficulty of the discrimination task. The experimental outcome, therefore, is consistent with non-attentive access to memory.

Returning to Posner and Klein's probe study discussed in the preceding section, recall that probe reaction time begins to rise prior to the expected time of the second letter to be matched. LaBerge's study yields additional insight into the behavior of probe reaction time. Apparently the encoding of the first letter is not attention demanding. But as the time for the second letter approaches, a selector mechanism is turned to the letter in memory that has already been encoded. Once the selector mechanism is committed, occurrence of the probe requires switching and increases reaction time even though some features of the probe may be processed during switching.

A similar explanation may be invoked to explain an apparent discrepancy with the Posner and Klein results. Comstock (1973) exposed the first of two letters to be matched for only 15 msec and followed it with a masking stimulus. Under that condition, probe reaction time began to rise much sooner than in Posner and Klein's study, suggesting to Comstock that encoding the first letter was attention demanding. Alternatively, when subjects anticipate that the results of encoding will be damaged by a mask, a selector mechanism may be turned to the first letter resulting in an increase in probe reaction time. The encoding itself may require no attention.

There is another important aspect of LaBerge's experiment. An unexpected signal can occur in the context of expecting either a detection or a discrimination. Reaction time to an unexpected signal was 354 msec when the expected one was to have been detection, but 432 msec when the expected one was to have been discrimination. It appears to take longer to switch the more difficult the expected signal.
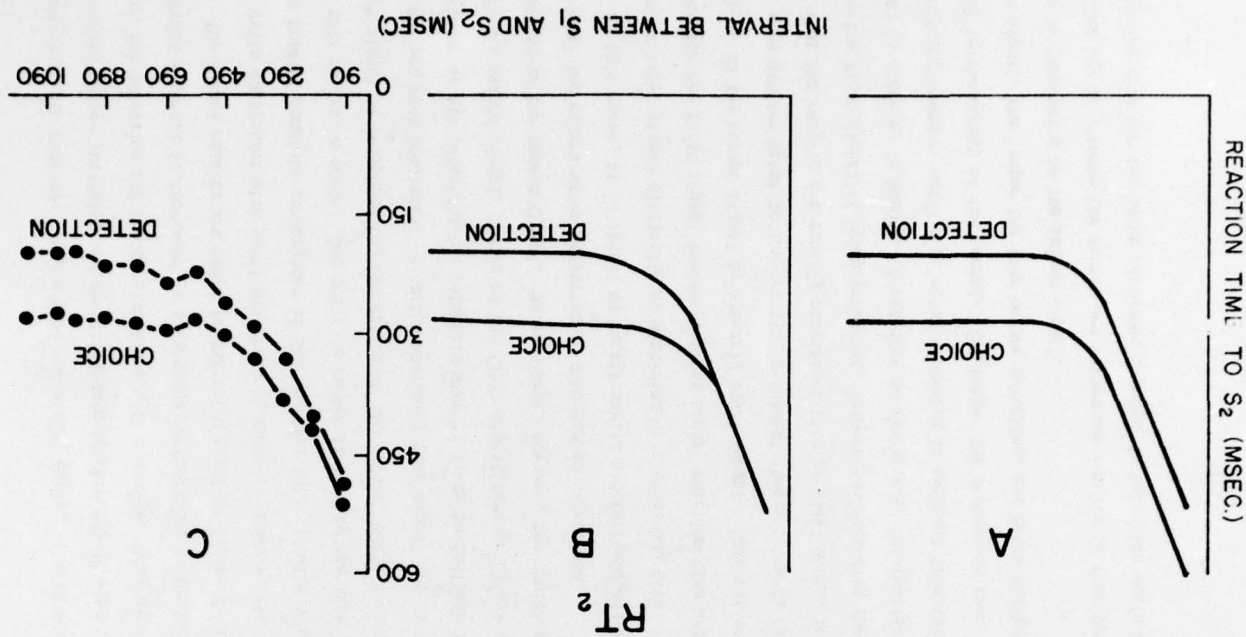
Figure 4. Panel A shows the single-channel prediction for reaction time to a signal when it requires detection or choice. Panel B shows predictions for a theory of parallel access to memory followed by interference at a later stage. Panel C shows obtained results from Karlin and Kestenbaum (1968).

A slightly more complicated experiment by Karlin and Kestenbaum (1968) used logic similar to LaBerge's to make the same point about attention demands of memory retrieval. The logic again places the attentive mechanism on one signal and observes what processing has occurred for a second signal of variable difficulty. One of two digits appeared as a first signal[3] and was responded to first with the left hand. At a variable interval after the first signal and ranging from 90 to 1150 msec, a tone occurred for the second signal, requiring a button press with the left hand. In one condition only one tone could occur requiring detection. In the other, one of two tones could occur, requiring a choice response. Task difficulty was varied differently than in LaBerge's study, but the logic was the same: Attention is directed to one signal, which in this case requires a response, and then attention is switched to a second signal. Although the second response will certainly be delayed, the processing it has received can be assessed by the difference in reaction times between the detection and choice situations.

Both single-channel theory and allocatable capacity theory lead to the same prediction, as shown in the left panel of Figure 4. If all processing regarding choice of the second signal is delayed until the first signal

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Insert Figure 4 about here
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is processed, choice will take longer than detection by a constant amount, yielding an additive relation between interstimulus interval and choice difficulty. The prediction is the same if some capacity is directed from the first to the second signal. The prediction for parallel access to memory is shown in the middle panel of Figure 4. While processing the first signal, the second signal is also processed, but the selector mechanism cannot be switched to the accumulated output of signal two until the first

signal has been cleared. When signal two occurs early, it will often be processed before switching and the difference between the delayed reaction times for detection and choice situations will diminish. Thus as inter-stimulus interval is increased, a divergence in functions is predicted.

The actual results are shown in the third panel of Figure 4, and they are quite consistent with parallel access to memory. However, the theory does predict complete convergence at the shortest interstimulus interval, and this failed to occur. One possible reason is that by the time the first signal is responded to, processing of the second, while in progess, has not yet been completed. A second reason is that signal one is responded to slower at all interstimulus intervals when it is to be followed by a more difficult second signal. Delay of the first signal further delays switching attention to the second signal. By and large, however, the choice decision of signal two occurs while attention is diverted to signal one.

At this point, it is useful to recall Karlin and Kestenbaum's manipula-tions of first signal difficulty as mentioned in the introduction. Increased choice for the first signal increases first signal reaction time and delays response to the second signal by a nearly equal amount. Observations of this sort were earlier taken to support single-channel theory. Now it can be seen that the results are equally consistent with parallel access to memory. While the first signal is being processed, information regarding the second signal is accruing in memory. A response to the accrued information cannot be emitted, however, until a selector mechanism is switched from the first signal to the output of the second. The longer the processing time of the first signal, the longer the time before switching, and hence the greater delay in responding to the second signal.

One way of viewing the Karlin and Kestenbaum results is that total processing time for two tasks performed together is less than would be

predicted from reaction times when the tasks are performed separately. Such failure of additivity was also found by Schvaneveldt (1969) when he manipulated number of alternative stimuli and responses and compatibility of stimulus-response relations. This study is particularly important because variations in stimulus-response compatibility obviously influence the time to retrieve the response from memory. Thus if non-additivity is found it is a powerful demonstration of the automaticity of retrieval.

A digit appeared in one of two displays in front of the subject. In the simplest situation the subject named the digit and pressed a response button on the same side as the lighted display. The total reaction time to complete both tasks was 469 msec. When digit complexity was increased by requiring the subject to add one and respond with the sum, total reaction time increased 110 msec to 579. When spatial complexity was increased by requiring a button press by the hand opposite the displayed digit, total reaction time increased by 46 msec to 510. When both tasks are increased in difficulty, single-channel theory predicts an additive increase of 156 msec (110 plus 46). The actual increase, when both tasks are increased in dif-ficulty, was only 127 msec, very little more than the 110 msec increase demanded by complexity of the digit task alone. Most of the additional spatial task time is absorbed in the increased time demanded by the digit task, suggesting again that transforming input code to output code occurs in parallel for the two tasks.

Similar results were found by Schvaneveldt when number of alternatives was varied. When both the verbal and spatial task required simple reactions total reaction time was 356 msec. A two bit verbal decision increased total reaction time to 607 msec. A two bit spatial task increased total reaction time to 571 msec. But when both tasks were increased in difficulty, total reaction time was only 670 msec, considerably less than the 833 msec expected
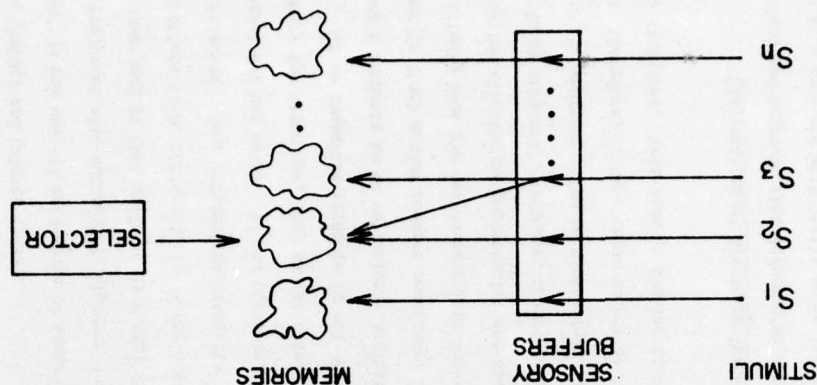
Figure 5. A schematic representation of parallel access of signals to memory followed by a mechanism that selects one activated memory or another.

were verbal and spatial decision additive in time as expected by single-channel or allocatable capacity theories.

What justification is there for the supposition that discrimination difficulty, number of stimulus alternatives and stimulus-response compatibility affect memory retrieval rather than some other process such as sensory encoding? Basically the effects of both stimulus discriminability of the LaBerge sort and number of alternatives are magnified when the mapping to response is less compatible (e.g., Brainard, Arby, Fitts & Alluisi, 1962; Broadbent & Gregory, 1962, 1965). Thus the manipulated times appear primarily to be the times to retrieve the appropriate response. The studies by LaBerge, Karlin and Kestenbaum, and Schvaneveldt lead to the conclusion, therefore, that memory retrieval is largely nonattentive.

Transforming of Information Into Action

Numerous phenomena converge on the conclusion that more than one stimulus simultaneously activates information stored in memory. In addition to redundancy gain, filtering, probe reaction time, and retrieval time phenomena, others such as processing sequential information (Keele & Boies, 1973), combining signals into a single response (Keele, 1970), and the superiority of word perception over single letter perception (Reicher, 1969) argue for the same conclusion.

The general model that emerges is portrayed in Figure 5 and may be contrasted with Figure 1. Information enters the sense organs and, barring peripheral masking, activates sensory representations. Sensory information in turn leads to the parallel accrual of memory information. One source of sensory information can diverge to more than one memory; more than one sensory source can converge on the same memory. However, for the information activated

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Insert Figure 5 about here
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in memory to be converted to action, a selector mechanism must intervene, allowing subsequent operations such as releasing a response, rehearsing the activated memory, matching it to some other memory, and so on. This view is basically similar to earlier ones by Deutsch and Deutsch (1963), Norman (1968), Morton (1969c) and LaBerge (1975).

One may fairly ask why, if activation of memories is automatic, are not the final responses also automatic? Why does interference occur near output? The answer may be that while it is useful to the organism for all stimulus associations to be activated, it is not useful for all possible actions to be released. Once information associated with a stimulus is available, several options exist. If the activated memories are to be stored in episodic memory for later use, they can be rehearsed; but if not, rehearsal may be avoided. If an immediate response is not desired, then it would be deleterious were a response to be reflexively activated. A selector mechanism at a point prior to final action appears necessary, therefore, for coordinating information available from the environment with information regarding goals. Together information elicited by the stimulus and goals determines whether the action should be rehearsal, response, counting, comparing, searching for more information, or whatever. The mechanism that determines one action or another appears, therefore, to be a major source of limit, corresponding to what we mean by attention. This view is similar to one promulgated by Shallice (1972).

Elaborations of Attention Theory

Evidence discussed suggests that information accrues at more than one memory location at a time and with little or no interference. But other experimental results following closely similar logic fail to support parallel accrual. Attempts must be made to rectify the discrepancies. Moreover, the model evolved places selectivity only late in the processing sequence. That assumption may be wrong and under some circumstances earlier selection may occur.

Problematic Results for Parallel Access to Memory

Conrad (1974), as described earlier, used a variation of the Stroop effect to show that more than one meaning of an ambiguous word is activated, even in the context of a disambiguating sentence. Recently, however, Schvaneveldt, Meyer and Becker (1976) using a different paradigm failed to confirm this result. Subjects classified letter strings as words or nonwords by pressing one of two response keys. Earlier they had shown that when two related words occur in succession (e.g., Bread followed by Butter), the time to decide the second item is a word is reduced over an unrelated word. Thus the occurrence of one word appears to activate other related words in memory. In the present study, three successive letter strings were presented in a block. Sometimes a triple such as River-Bank-Money was presented. The middle word is related to the first, and it shows the usual relatedness effect. The middle word itself has two meaning, however, and the second meaning is related to the third word. If both meanings of the ambiguous word are activated, as suggested by Conrad's Stroop study, then facilitation of the third word ought to be observed. But such facilitation was not found. These results appear to support a model of selective rather than parallel access to memory: The meaning of the first word determines which meaning of the second is accessed. The conflict between Conrad and Schvaneveldt, Meyer and Becker is not adequately resolved. Perhaps one paradigm or the other is at fault. Perhaps complicating explanations are needed. At any rate, the conflict necessitates some caution regarding conclusions reached at this point.

Becker (1976) more recently used the word-nonword (lexical) decision task in conjunction with the Karlin and Kestenbaum paradigm. The first of two signals was a letter string requiring a word or nonword response. At either 90 or 190 msec following the letter string a tone occurred, requiring

a second response. The tone task could be simple or choice, and control conditions showed the choice to be 141 msec slower than simple reaction time. If the word decision requires no attention through the encoding stage, the tone should be processed during the encoding of the word but not responded to until a selector mechanism can be switched to it following response to the word. Thus when the tone follows a letter string, the difference between simple and choice reaction time should diminish or even vanish. This result did not obtain, however. When the tone followed 90 msec after a high frequency word, simple and choice tone reactions differed by 264 msec. When a tone followed a low frequency word, the difference was even larger at 348 msec. Both values are much larger than the 141 msec difference found in control conditions. These results dramatically differ from those of Karlin and Kestenbaum and of LaBerge (1973). Obviously, something either in the encoding of the word or tone is requiring attention.

Becker also more exactly replicated Karlin and Kestenbaum's study using digit identification as the first task and again found that the difference between simple and choice tone reaction time did not diminish when it followed the first signal.

Diffuse memory activation and coordination of codes. Why do Becker's results differ so sharply from what would be expected based on the previous theory? An important experimental difference pointed out by Becker (personal communication) is that most of the studies described earlier involved either very few alternative stimuli and responses or large amounts of practice or both. In contrast, Becker's subjects never saw the same letter string more than once during the course of the experiment, and the number of experimental sessions was small.

A possible resolution could take the following approach. When a stimulus appears, consistent with previous theorizing, information stored in memory is

automatically activated. In many situations, particularly with words, a large amount of information is activated. A word such as SAW may activate the concepts of wood saw, tool, hammer, lumber, and other meanings such as "to have seen". Studies by Conrad (1974) and Warren (1972) using the Stroop effect provide good evidence for such broad activation. Moreover, if this forward activating process is imprecise, SAW may also activate other items such as sow, paw, how, sam by virtue of physical similarity. Nonwords, to the extent that they are physically similar to real words, may also activate several memories. The great spread of diffuse activation may prevent a subject from deciding the exact identity of a stimulus unless an additional verification process is invoked. Concepts or meanings activated in memory also have other codes associated with them. For example, the concept saw, once activated, may in turn activate an orthographic code detailing how it is spelled. By comparing the orthographic code with the actual input, the exact stimulus can be verified.

To put the notion another way, a stimulus may activate physical codes, orthographic codes, phonemic codes, and semantic codes. Within the semantic area a large number of meanings may simultaneously be activated. An attentional mechanism is one that coordinates information of goals with what is activated in memory. It also is one that may coordinate information available in different codes.

This view is quite consistent with the one that evolved earlier. Information may accrue simultaneously in different memory locations. The attentive process may link the different codes to each other, resulting in a precise identification of the stimulus.

The idea of diffuse but parallel memory activation followed by a limited process that coordinates information in memory is largely suggested by Becker's (1976) verification model, though it differs in details. It

is also similar to Collins and Loftus' (1975) idea of spreading activation in semantic memory but with attentional control of the linkage between the semantic system and a dictionary system that contains phonemic and ortho-graphic information.

How does this generalized model deal with Becker's data on the one hand and the earlier data on the other? When the number of possible stimuli and responses is very limited and practice is high, the activation of a specific memory by a specific stimulus may be sufficient to precisely match stimulus with response. Under those circumstances, results such as Karlin and Kesten-baum's may be obtained. But when practice is low or many different stimuli are used, as in Becker's study, so many memories may be activated that at-tention demanding processes are needed to coordinate codes.

What useful function would be subserved by diffuse activation in memory if it requires attention demanding operations to further specify stimuli and choose responses? First, despite the diffuseness, the number of concepts activated would be tremendously less than the totality of memory, greatly simplifying memory search. Second, most information processing occurs in contexts that further reduce the relevant memory locations. Together context and stimulus may so greatly converge on one meaning that often little or no verification is needed.

Implications of dyslexia. The general idea of widespread memory activation and subsequent code coordination receives a great deal of support in recent literature, and it will be reviewed in greater detail later. However, in-vestigations by Marshall and Newcombe (1973) and Shallice and Warrington (1975) of dyslexic patients, people having great reading difficulty, provide striking support for the model. Because the studies so clarify the general proposition, it is useful to mention them at this point.

The dyslexic patients studied all had learned to read at one time and then suffered brain damage that impaired reading. Because prior reading had been established, certain errors occur that otherwise would not be ob-served. Some dyslexics mistakenly read words that are physically similar to the ones actually presented. Chair may be substituted for charm, dug for bug, wash for was, and so on. For other dyslexics visual errors seem par-ticularly triggered by letters that have more than one pronunciation. For example, incense may yield increase, triggered by the ambiguity in how to pronounce the letter "c". Guest may similarly yield just. The most illuminating class of dyslexics, however, yield errors not only of physical confusion but also very often errors of semantic confusion when reading individual words. Speak yields talk, employ yields factory, found yields lost, hurt yields injure.

What are the implications of such semantic errors? They appear to support the contention that a word leads to very diffuse activation of con-cepts in semantic memory. Such activation by itself is not sufficient, however, to pinpoint the precise word. The semantic dyslexic appears to have sustained damage to a mechanism that allows such pinpointing. Either visual or phonemic codes have been lost or the verification mechanism that coordinates visual, phonemic and semantic codes is impaired. It may be that visual dys-lexics suffer a similar impairment but of lesser degree. When the impair-ment is partial, some verification occurs, eliminating words that are seman-tically related but physically very dissimilar, but concepts activated in memory that are physically similar (e.g., dug-bug) escape accurate verifica-tion. Under more severe impairment, it appears that little verification occurs in that practically any item activated in memory by the stimulus may be reported.

Marshall and Newcombe note that errors similar to those of a semantic dyslexic occur also for normal readers in tachistoscopic presentations, and they can sometimes be observed in reading where one word is more appropriate in a context than a word actually presented. Thus it is likely that conclusions derived from the dyslexic apply also to the normal reader.

Optional filtering and structural interference. The general idea about attention that is emerging is that it is a mechanism that coordinates information activated in the different memory systems. Sometimes the coordination may be among different codes. Sometimes it may be between activated memories and other goals. Other controlling capabilities may also exist. In particular there may be situations in which two sources of information mutually interfere at a rather peripheral level of processing, and some control may be exercised at that level. This view, of course, is similar to Broadbent's (1958) traditional filter theory, but it differs in suggesting that the control is optional and that it may be most likely for structurally interfering signals.

Consider a situation posed by Ninio and Kahneman (1974). Subjects monitored an auditory list of words for an animal name, pressing a key when they heard one. In one situation, subjects monitored messages to both ears; in another they ignored words on one ear and listened to the other. Which situation results in the fastest reaction time to an animal name? If the words on both ears are simultaneously encoded without interference, and if a selector mechanism is attuned to the animal location of memory, the divided attention situation would be as fast or faster than the focussed condition. In the focussed condition people might be slower because they also have to be sure that the word is from the correct ear.

In fact, Ninio and Kahneman found divided attention to be slower, not faster, by about 135 msec and to result in more missed animals. One interpretation invokes a serial decision process at some point. Each word could be

encoded in parallel and tagged for location of entry. In the divided case the selector mechanism must then serially interrogate twice as many items activated in memory as in the focussed case. Alternatively, first the word from one ear and then the word from the other ear could be encoded, as supposed by traditional filter theory. Both explanations predict that reaction time variance should be greater in the divided situation. If a person is attending to the correct ear when an animal name appears, he will be fast; if he is attending to the incorrect ear he will be slow. The mixture of fast and slow reaction times will lead to high variability.

Variability, however, was not much greater in divided than focussed attention, and analysis of the reaction time distributions showed no evidence for bimodality, invalidating a serial switching model. Apparently both messages were processed to the memory level in parallel in the divided situation and the selector was attuned to the "animal area" of memory.

In a similar study by Treisman and Fearnley (1971), subjects in one condition heard either a single nonsense syllable or a digit. In the other condition they heard a pair of items, one in each ear. If they heard a digit they were to press one key, otherwise they were to press another key. Sometimes they were cued in advance which digit to respond to, but other times any digit required a digit response. Now, when only a single item occurred on only one ear, the unknown digit was responded to slower than the cued digit by about 103 msec.

What would be expected when the digit could appear on either ear? If the two items to the two ears are serially encoded, the unknown digit should take longer than the cued digit by about 154 msec, which is 50 percent larger than 103 msec difference when subjects focus on one ear. If the correct ear is selected first, then the cued digit can be identified 103 msec faster than the non-cued digit, but if a digit does not occur on that ear, the subject must switch to the other ear and attempt identification again, doubling the

total time difference. Averaging the switch and non-switch trials together leads to a predicted 50 percent increase in the difference score. However, as in the Ninio and Kahneman study, reaction time increases in the divided attention situation over the focussed situation, but the increase is about equal for both the cued and non-cued cases, leaving the difference between them approximately the same at 92 msec. This study too leads to the conclusion that items on both ears are simultaneously encoded, but at a cost. Why the cost?

Ninio and Kahneman suggest that encoding requires processing capacity, but that the capacity can be allocated all to one ear or divided between the two ears allowing parallel but slower processing on both. Another possible explanation is that auditory messages to the two ears tend to mask each other or merge with one another, making discrimination more time consuming. When subjects are instructed to attend to one ear, however, the message from the other ear can be partially filtered (attenuated), reducing masking. This possibility is similar to single-channel or filter theory, but differs in two important ways. One is that filtering is optional and sometimes processing to memory may occur in parallel. The other is that mutual interference is closely tied to the structures doing the processing. Two inputs coming through a structurally related system such as the two ears may interfere more with each other than two inputs coming through different structures. This view is actually quite similar to those held by Treisman (1969).

Some evidence for optional filtering and the reduction of masking comes from a study by Hawkins, Thomas, Presson, Cozic and Brookmire (1974). A briefly presented tone was followed by a second masking tone that tended to bias identification of the first in the direction of the masking tone. Such masking also normally occurs when the masker is presented to the ear opposite

the tone to be identified. However, when subjects know in advance both that the masker will be in the opposite ear and know its frequency, masking is markedly reduced, suggesting that the masker is filtered by ear and frequency.

One implication of a masking type explanation of task interference is that the decrement in divided attention should be highly sensitive to the similarity of the two inputs. Little study has been devoted to this important issue, but some evidence appears to support it. Treisman and Davies (1973) required subjects to monitor simultaneous messages for the occurrence of animal names. The simultaneous words were both visual, both auditory, or one auditory and one visual. Detection of animal names was considerably higher when the messages were divided between the two modalities. In fact with two modalities there was little difference between attention divided between the two message sources or focussed on only one message.

Structural interference from similar input signals may only be apparent when signal discrimination is relatively difficult. When signals are simple or practice extensive, little decrement for structural reasons may be apparent. Schwank (1975) presented two signals in succession, requiring a response to each. The response to the second signal was delayed, a typical effect, but the delay was no greater when both signals were colors or both were letters as opposed to one letter and one color. Greater structural interference might have been expected when both were letters or both colors, but the stimuli were simple and non-confusable, and the major portion of processing time may have been in retrieving the appropriate response rather than differentiating the signals.

Ostry, Moray and Marks (1976) likewise found that by 5-10 sessions of practice subjects could monitor digits to both ears for occasional letter targets as efficiently as they could monitor a single ear. Similar results were found when monitoring for animal names mixed amongst non-animal names.

Here the simplicity of stimuli and/or large degree of practice may overcome structural problems.

Although critical studies are few in number, leaving considerable leeway for other interpretations, a tentative conclusion places some constraints on the model developed earlier. When complex, similar stimuli come simultaneously through the same modality, the stage is set for masking, merging of signals, or signal confusability. Some protection against mutual interference is provided by filtering or attenuation of one message prior to memory, much as claimed by Broadbent and Treisman in early theories. However, filtering or attenuation appears optional and parallel access to memory can occur, though it may add delays to processing time and increase errors. When signals are less confusable, parallel access to memory appears to incur little or no additional cost. The idea of attention as a control mechanism that can set filter location is quite consistent with the idea that an attentional mechanism coordinates codes.

Codes and Code Selection

The two ideas of attentional control, one of very diffuse activation in memory followed by coordination of codes, and the other of flexibility in filter location, require further development to appreciate the great deal of diversity exhibited by the processing system. A primary point to be made is that presentation of a stimulus elicits not only several items within a coding system, such as several meanings, but also different codes, and the activation of more than one code is also done in parallel.

The notion that the stimulus may elicit information in two different coding systems stems partly from observations by Posner and Mitchell (1967). Subjects classified letter pairs as the same or different by pressing keys. When the letters had not only the same name but the same shape (e.g., Q and Q), classification was about 50 to 100 msec faster than when the letters had the

same name but differed in shape (e.g., Q and q). This difference in speed would not be expected were subjects selecting only on the basis of a name code. Instead either visual or name codes appear to be used for matching, and under simultaneous presentation the visual code is faster.

The Posner and Mitchell results could reflect differences in _level of coding_ with the visual code preceding and being necessary for the name code. Other observations suggest, however, that this view is incorrect. If the letters to be matched are flanked by visually similar letters, the time for a physical match is slowed but the time for a name match is not (Posner & Taylor, 1969). If the physical code preceded the name code, then slowing the physical code should also slow the name match. Conversely, if two letters have the same name, that fact does not necessarily slow the subject in responding that they are physically different. Cohen (1969) had people match strings of three unrelated letters. If any letter between the two triplets was different, subjects were to say different. When different letters were physically similar matching was not slowed. Also when different letters were similar in name, matching was not slowed. Only when items were confusable on both counts was reaction time increased. This suggests that both codes are independently processed. Finally, Corcoran and Besner (1975) showed that when two letters to be matched differ in size or in brightness, the differences affect physical matches but not name matches. Again, if the physical code was a necessary precursor of the name code, then factors that affected physical matches should also affect the name match. A number of other examples that make the same point are cited by Posner (in preparation).

Results of this sort suggest that, rather than differing in level, the two codes, physical and name, are independently manipulable and derived in parallel with mismatches being determined by whichever code is first finished.

Studies of word perception also indicate more than one code is available. First, it is clear from earlier cited studies (Conrad, 1974; Marshall & Newcombe, 1973; Schvaneveldt, Meyer & Becker, 1976; Shallice & Warrington, 1975; Warren, 1972) that words activate semantic codes--i.e., synonyms, associated words, and perhaps alternate meanings become activated by a word. The written word also can activate a phonetic representation, a physical representation, an orthographic representation, and perhaps a more general visual code.

Since Reicher (1969) and Wheeler (1970) it has been known that letters from single syllable words are perceived in tachistoscopic recognition as accurately or more so than isolated letters. This perceptual superiority occurs not only for real words but also for pronounceable nonwords (Baron & Thurstone, 1973). Because the pronounceable nonwords have no meaning, their superiority must be due to either the pronunciation, orthographic, or spelling rules of English.

Hawkins, Reicher, Rogers and Peterson (1976) very briefly presented an item such as SENT followed by a word pair such as SENT and CENT. Subjects had to indicate which word they had seen, and because of the brief visual exposure, they often made errors. Both alternatives in the example are pronounced exactly the same--i.e., they are homophones. If the perceptual superiority of words is sometimes based on a phonetic code, even though the word is visually presented, then subjects should have more difficulty with homophonic pairs than with control items (e.g., SOLD followed by SOLD and COLD) in which the critical letters are pronounced differently. As long as homophone test pairs were not very frequent, they indeed resulted in less accuracy than the control pairs--58.3 percent correct versus 72.5 percent correct. These results support the contention that a phonetic code is activated by the visual presentation of the word.

On the other hand, Pollatsek, Well and Schindler (1976) demonstrated word superiority that must be attributed to an orthographic code rather than a phonetic code. They presented two letter strings and asked subjects to respond same only if all letters between the two words were physically identical. Earlier Eichelman (1970) had shown that actual words were matched faster than nonword strings, even under physical match instructions, but this could be attributed to the use of a name code in the visual condition. Pollatsek et al. avoided this interpretation by using mixed case letter strings (e.g., leAF). Such a string has little visual familiarity but it is orthographically familiar. Subjects were able to say that a pair such as leAF and lEAF were physically different more rapidly than nonword strings of the same length. If the match were being made on a name basis, interference should occur. Because facilitation occurred instead, the results support the independent existence of an orthographic code.

Familiarity may also be based on yet other codes (Henderson, 1974). People match familiar acronyms such as FBI, USSR and IBM faster than they match non-familiar letter strings such as BFI, RSSU and IMB. The familiar acronyms are neither phonetically nor orthographically regular. The basis for faster matching must therefore be either visual or semantic familiarity.

Finally, Rogers (1975) examined the activation of codes for faces. Line drawing faces that varied in similarity were associated to names that also varied in similarity. Subjects were presented with a name followed by a face or vice versa and indicated whether they matched. When the face belonging to a presented name was similar to a subsequently presented face, judgments of difference were impaired, indicating that visual codes were being used in the match. Conversely, when the name belonging to a presented face was similar to a succeeding name, judgments of difference were again impaired. Thus it appears that either faces or names can activate face or

Evidence for code control also comes from Carlton James (1975). Subjects classified letter strings by pressing one button for words and another button for nonwords. In one experiment the nonwords were pronounceable. The words were either high, medium, or low in English language frequency and were either concrete or abstract in meaning. Concreteness had no effect on reaction times to high frequency words (616 msec), but low frequency concrete words were faster (665 msec) than abstract low frequency words (745 msec). Apparently high frequency words are so familiar at a visual level that a decision is made prior to semantic influences. Low frequency words are less familiar visually, and the semantic aspects of concreteness versus abstractness influence reaction time.

Similar results occur when the nonwords are not only pronounceable but are also homophonic to real words, ruling out the possibility that high frequency words were judged on phonemic familiarity rather than visual familiarity. However, when the nonwords were all made non-pronounceable, reaction time speeded considerably and the effects of word frequency and concreteness were nearly abolished. Subjects apparently shifted to a phonemic strategy for word decisions.

Although these studies by Hawkins et al., Johnston and McClelland, and James argue that people have some code control, individuals probably also differ on the weighting given to different codes. Baron and Strawson (1976) asked people to rapidly read aloud lists of phonemically regular words or lists of phonemically irregular words (e.g., tongue). Some people read phonemically regular words faster than irregular ones. Baron and Strawson suggest that those people transform the visual presentation to a phonemic code and then articulate it, and these people are therefore called Phonecians. Other subjects show less difference in pronunciation time for the two types of words, appearing to transform a visual code to semantics and then to

name codes on which subsequent matches are based. When simultaneous name-face pairs are matched, both face and name confusability effects occur suggesting that both codes are activated at the same time.

Code selection and integration. How are the numerous codes coordinated into a final response? Perhaps all codes converge without attention on the final response. The earlier attempt to reconcile Becker's results with parallel access to memory suggested, however, that attention is used to select and combine codes. If this is true, then the type of code used in word perception should be flexible, varying with task demands. Moreover, individual differences may exist in the use of codes.

The Hawkins et al. study that provided evidence for phonemic codes also showed that phonemic codes are damped when their use would be detrimental to success. When a target such as SENT is followed by homophone tests such as SENT and CENT, recognition impairment occurs only when homophone test pairs are rather rare in the experiment. When homophone test pairs frequently occur, the phonemic strategy would obviously be a poor one, and subjects' code selection appears to change: choice between homophones is no worse (66.5 percent correct) than choice between non-homophone controls (67.8 percent correct). Both control and homophonic cases are superior to single letter recognition (53.8 percent correct), demonstrating that the codes adopted, while not phonemic, still take advantage of word familiarity.

Johnston and McClelland (1974) observed a paradoxical word recognition effect that bears on the same point. Subjects are superior in recognizing a letter in a word as compared to an isolated letter, but only when they are not informed in advance where the letter will appear. If they are told where in a word to look for the letter, paradoxically perception of the letter becomes worse. It appears that subjects can selectively attend either to a word code, deducing the letter from the word, or attend to the letter code. The latter appears less effective.

articulation or directly from a visual code to articulation. The latter subjects name the word as they would name an object without intervention of a phonemic code, so Baron and Strawson call them Chinese, based on the notion that reading Chinese characters is not mediated by a phonemic code.

Support for this dichotomy comes from two other tasks. On one task subjects attempt to decide whether pseudo words (e.g.,CAIK) are pronounced the same as real words. On the other task, subjects are given a spelling task on words that are commonly misspelled. During the initial spelling they cannot correct their answers. Then they are shown pairs with the correct spelling and an incorrect spelling and asked to choose the correct one. Some people improve spelling more than other people when they can see the words. Subjects good on the pseudo word task and poor on visual spelling correction were classified as Phonecians. People good on spelling correction and poor on the pseudo word task were classified as Chinese. This dichotomy was correlated with the degree to which people had difficulty in reading irregularly spelled words as opposed to regularly spelled ones. Thus one subject type appears to rely heavily on a phonemic code; the other type relies heavily on a visual code.

Baron and McKillop (1975) present related evidence for individual differences in the use of phonemic codes.

These individual differences are quite significant as further sources of evidence for different kinds of codes and for their practical implications for understanding reading.

The Snyder effect and related phenomena. The general point being made is: An incoming stimulus is broken into different features or codes, including semantic codes, that develop simultaneously. A later attentive process reintegrates selected features or codes into a unified percept. This point would be strengthened if it were shown that integration is occasionally

or even systematically in error. Snyder (1972) tachistoscopically presented a circle of 12 letters, all normal and in black ink except for one letter which was either fragmented, colored red, or inverted. Following a tachistoscopic presentation of the array subjects identified the letter that was altered. A frequent error was to misattribute the fragmentation, color, or inversion to a letter next to the one actually altered.

What is the implication of this error? When a stimulus is processed, different analyzers parse out and code different features of the stimulus. Concepts such as color, inversion, size, name and so on become activated. Only subsequently are the various codes integrated via the fact that they come from the same spatial location. To the degree that the spatial origin of the cues are uncertain, misassignments may be made.

The Snyder effect poignantly illustrates the processing system proposed. Stimuli enter the system and in parallel a variety of codes and meanings within a code become activated. It is only later that they are integrated and that an attentive mechanism exerts some control in the integration.

Improper integration of codes has also been observed in other settings, sometimes in a regular way, resulting in illusions. Deutsch (1975) noted that when a high and low tone alternate in one ear and the same sequence occurs one note out of phase in the other ear so that the high note in one ear coincides with the low in the other, listeners may hear only one alternating sequence, but it may switch from ear to ear. The high tone is normally heard by right handers in the right ear and the low tone in the left ear. An illusion is occurring because if subjects alternate ears in time with the notes they should hear a steady stream of high or of low notes and not an alternating stream. This and other musical illusions described by Deutsch indicate that messages to both ears are being analyzed for features and then reassembled.

In yet another case, Studdert-Kennedy and Shankweiler (1970) observed misassignments in phoneme perception. When a voiced consonant with frontal articulation (i.e., b) is played to one ear and simultaneously an unvoiced consonant with middle articulation (i.e., t) is played to the other ear, the voicing and place of articulation appear to be separately analyzed and then reassembled. Errors of assembly are more common than other errors with subjects reporting p and d more often than g and k. The error p involves combining the unvoiced feature from one ear with the feature of frontal articulation from the other ear. The error d involves the other misassignment, whereas errors g and k both import a feature not presented.

Costs and Benefits of Selection

A selection system that can optionally select information at an early stage reduces errors whenever complex signals in the same system mask one another. It also reduces errors when different codes lead to conflicting behaviors. And a selection system can select a subset of codes that meets the current demands of the task. However, these benefits of selectivity fail to capture one of the major aspects of a selective mechanism. The prior allocation of attention to a particular code or memory location within a code may greatly enhance the overall efficiency of processing even when there is no masking or conflict.

When a signal occurs, information regarding it accrues in memory to some criterion at which time the information can be selected and related to other codes or goals. The selective system may take a measurable amount of time to operate. If the selector is uncommitted, selection may take more time than if a prior expectation for the stimulus is established. Thus occurrence of an expected signal should result in a reaction time benefit. Conversely if an unexpected signal appears, the selector must switch from an already committed state, incurring a reaction time cost. Overall efficiency would increase whenever benefits occur more frequently than costs. In essence, a selective attentional mechanism would help to efficiently use redundancy in any skilled setting.

Does attention switching make sense--namely can costs and benefits of switching be measured?

The answer is not simple, for another mechanism also exists that generates costs and benefits in reaction time. Expectation can lower the criterion amount of information that must be accrued in some memory location before leading to further decisions. If the expected signal does occur, on the average it will reach criterion sooner than it would were the criterion not lowered. However, the criterion shift model makes a specific prediction not made by attention switching: An unexpected signal will often reach the criterion for the expected memory, resulting in a false alarm, and such false alarms will occur more often than a neutral condition with no expectation. Thus confirmation of the switching concept requires paradigms in which criterion shifts are a less plausible interpretation.

One such paradigm by LaBerge (1973) was discussed earlier for a different purpose. LaBerge primed a person to expect either a color or a tone. When an unexpected signal occurred reaction time was considerably increased. This cost cannot easily be explained by a criterion shift as subjects had to make the same response regardless of signal. If the response criterion were lowered by the expectation, either signal should benefit. Since cost rather than benefit occurred for the unexpected signal, the effect appears due to attention switching. The conclusion is further bolstered by the observation of longer switching time the more difficult the expected signal. This is not easily explained by a criterion shift. Also the earlier point of LaBerge's study was that information about the unexpected signal was accruing prior to switching. Again, that evidence is difficult to accomodate by a criterion shift because when the criterion is raised for an unexpected signal, it should increase reaction time more for a difficult than for an easy signal. In fact, LaBerge found the opposite to occur. So LaBerge's experiment makes

the important point, in addition to automatic accrual of information in memory, that a selective device can be preset to receive the memory output from a particular signal.

Another paradigm that supports the switching concept has been developed by Posner and colleagues. Posner and Snyder (1975) had subjects match a pair of letters as same or different. In a high validity condition, a priming letter preceded the pair, indicating an 80 percent chance the primed letter would be in the pair. Because of the high predictability, subjects should switch their attention to the area of memory called for by the prime. In another condition, the prime was valid only 20 percent of the time, so it should not induce an attention shift. In a control condition the prime was replaced by a neutral warning signal. It is important to note that the prime in the high validity case did not differentially predict a same or different response, but only that the primed letter was likely to occur in the pair. Because of this, criterion shift explanations are less attractive.

When an expected signal occurred in the high validity condition, same reaction times were about 50-80 msec faster than following a neutral prime. This reaction time benefit began to develop the moment a priming signal occurred, and although the exact time course is uncertain, it reached near asymptote when the priming signal led the letter pair somewhere around 150 msec. When an unexpected signal occurs in the high validity condition, same reaction time is slowed by about 40-50 msec relative to the neutral condition. The cost does not begin to accumulate until perhaps 150 or more msec after the priming signal.

Attention switching would suggest that benefit and cost would occur at the same time. Yet benefit begins to accrue before cost. Two different mechanisms appear to produce benefit--one begins at the time the prime occurs and the other, related to attention, begins later. The first source

of benefit is called pathway activation by Posner and Snyder. The prime automatically activates the memory to which it feeds, even when attention is not directed toward that area. Considerable evidence for automatic activation was developed earlier. The prior activation facilitates the processing of any other signal using the same pathway.

Pathway activation is isolated in the low validity condition in which the prime has little predictive validity for the following letter pair. A modest reaction time benefit of about 30 msec occurs when the succeeding letter pair contains the prime and the benefit begins to accrue the moment the prime is presented. However, the low validity condition produces no cost, indicating that no attention was deployed to the prime.

The main features of the Posner-Snyder results have been replicated by Neely (in press) using word versus nonword decisions and priming with other words. He separated automatic and attended components of benefit in another way. In one condition, subjects were told that if BIRD appeared as a prime, they should expect a bird (e.g., ROBIN) for the lexical decision. Here both automatic and attended components should occur. In another condition, subjects were told that if primed with BUILDING they should expect a body part (e.g., ARM). In this case attended benefit should occur but no automatic benefit, since building is not associated with particular body parts. As expected, benefit occurred at the shortest prime interval (250 msec) in the first case but not later in the second case. In both cases cost developed after a 250 msec prime-to-word interval.

Studies of cost and benefit can be summarized as follows: When a signal occurs, information well associated in memory with the stimulus is automatically activated. This conclusion concurs with earlier ones and presents another line of evidence. For the activated information to be translated into action, a selector must be turned to the activated area

of memory. If the selector is preset to the expected memory area, reaction time will benefit if the expected signal in fact appears; reaction time will suffer cost if an unexpected signal appears.

Implications of cost-benefit analysis for the study of flexibility. Cost-benefit analysis suggests a possible way to study flexibility of attention. Though flexibility appears to be an important attribute of attention, it has received scant study, perhaps because of lack of a theoretical structure.

The importance of flexibility has been suggested by Gopher and Kahneman (1971) and Kahneman, Ben-Ishai and Lotan (1973) investigating Israeli pilots and bus drivers. Drivers and pilots were administered a dichotic listening task in two parts. In the first part a tone indicated which ear to attend to. Digit-word and word-word pairs occurred on the two ears and subjects were to report only the digits on the cued ear. Immediately following 16 pairs another tone occurred, directing attention to the relevant ear for part two. Part two involved three pairs of digits, and subjects reported the digits on the cued ear. Errors of shadowing on neither part one nor part two when run in isolation were predictive of either pilot success or bus driving accidents. However, when part two immediately followed part one, errors on part two were correlated about .35 with pilot rating in two samples and bus driving accidents in a third. These modest correlations are rather impressive considering that the pilots had been preselected on other criteria, that pilot ratings are of low validity, and that bus driving accidents, even when corrected for fault, are extremely chance dependent.

Why did dichotic errors on part two predict performance only when it immediately followed part one? According to Kahneman and colleagues, only in that situation were the subjects required to switch attention from one selective set to another. Flexibility of switching appears to be an important part of piloting and driving.

The Kahneman studies suggest that flexibility is a basic trait of attention on which subjects differ, but the concept has received little exploration. Perhaps flexibility in the dichotic listening paradigm is a different manifestation of reaction time cost in the LaBerge and Posner-Snyder paradigm, and this is a promising issue for further research.

Does selection involve inhibition? When one message is selected, what happens to rejected messages? One possibility is that selection is analogous to setting a gate for the selected material thereby facilitating it and equally blocking all other material. Alternatively, selection of one message may sometimes involve inhibition of others. A suggestive bit of evidence was provided by Treisman (1964b). If subjects shadow prose on the right ear it is more difficult to ignore two other verbal messages if one is in both ears and the other only in the left ear than if both messages are in both ears or both in the left. Likewise, shadowing a female voice is more difficult if two competing messages on the other ear are male and female rather than both female. These results suggest that not only is the relevant message selected, but competing ones are inhibited with inhibition being more difficult the greater the variability of unwanted messages.

More direct evidence for inhibition, using the Stroop effect, comes from Neill (in press). A color (e.g., red) prints out a color word (e.g., BLUE). The subject must respond to the color and ignore the word. Earlier it was suggested that both the color and the word activate their memory representations in parallel and a later process selects the color-activated memory. What happens to the word-activated memory? If during selection, the word-activated memory is inhibited, then the inhibited concept should be less available on the succeeding trials. Neill included some occasions in which the word on one trial became the color on the next trial. For example, on trial n the color red and the word BLUE require the vocal response

RED. On the next trial the color blue and the word GREEN require the response BLUE. If the response BLUE had been inhibited during selection on trial n, blue should be responded to more slowly on trial n + 1 than would an un-related color. Neill found reaction time on trial n + 1 to be 855 msec when the previously irrelevant memory became the relevant one, which is slower than the control reaction time of 823 msec. Thus some inhibition of the irrelevant message appears to occur.

The concept of inhibition in the context of selective attention is not well developed and it could use more investigation. Inhibition could, for example, be an element in explaining the discrepancy of the Conrad study and the Schvaneveldt, Meyer and Becker study on activation of ambiguous word meanings. Perhaps both meanings become activated and then as one is selected othersare inhibited. Thus whether the paradigm finds evidence for activation or inhibition may depend on the timing of events and other details of the experimental set-up. Indeed, by slight changes in paradigm, Neill was able to alter the outcomes of his experiment so that evidence for inhibition disappeared.

The Final Model

The analysis of attention has been rather drawn out and several side issues were delved into. Thus a brief map of the line of inquiry and a final statement of a model of attention would be useful.

The early theories of Welford and Broadbent placed selective attention at an early point in processing, between the sensory and memory systems. Only one signal at a time was transformed to a memory code. Stimulated by these theories, a great deal of subsequent evidence, while confirming limita-tions of processing, tended to place the limitations further into the sequence of processing, after the accrual of information in memory. The fate of irrelevant information, observations of redundancy gain, reaction time probes

inserted during encoding, and the effects of retrieval time on interference all suggest widespread, parallel access to the memory system.

In many situations, however, parallel access to memory entails costs. When stimuli are complex and in the same modality, they may mask or merge with one another; or if only one message is relevant and other codes or messages lead to conflict, then it would be to the organism's advantage to filter prior to memory. Some evidence does accord with that idea. It appears that optional filtering is related to structural limitations, being more likely when signals are from the same modality. Thus rather than viewing attention as always being invested at a particular place in proces-sing, it is better viewed as a control process that can influence the flow of information. When messages interfere with one another, the control pro-cess can attenuate one source of information prior to memory, although attenuation is quite likely incomplete (otherwise phenomena such as the Stroop effect would not be observed). When the messages do not interfere, they can be processed in parallel through at least the memory stage with no cost, and this is the primary point of the review.

Not only may different memory locations within a coding system be activated in parallel, but also different codes develop in parallel. A given word may activate physical, orthographic, phonemic, and semantic codes. This widespread and perhaps imprecise activation requires coordina-tion of the information, and it is at the coordination stage that an attentional process again exercises control. Some people suffering dyslexia appear to lack either specific codes or mechanisms for coordinating them. Cross matching of the different codes (what Becker calls verification) allows the normal reader to specifically identify the input item behind semantic activa-tion, but although error analyses indicate semantic activation with some dyslexics, they seem unable to cross match with a visual code. Results

from normal readers also indicate that the different codes do not automatically coalesce into a single decision. Instead optional control exists over which codes are used. Thus if many homophones on a test make phonetic discrimination difficult, people seem able to shift emphasis to another code. In addition to differences in codes used depending on circumstances, there are also individual differences in the facility of using one code or another.

One may ask whether word recognition requires attention. The answer is that some processes of recognition do not and other do. Many habitual associations and codes are automatically activated, too many for specific identification of the input. They require cross matching for specific identification and that process requires an attention mechanism. It is only when stimuli are few in number, practice is high, and strong context is available that recognition is non-attentive to the final percept. Even when these special features fail to narrow the field of activated memories to a large degree, automatic activation of associations would seem very functional. All the potentially relevant information regarding a stimulus will be activated and number of activated memories will be vastly less than the totality of memory.

The attentive mechanism that controls the selection and coordination of information from different codes can be preset for information to accrue in particular memories or particular coding systems. Such presetting takes advantage of redundancy, improving overall efficiency. Whenever expecta-tions are confirmed, processing time benefit occurs; on rarer occasions when expectations fail, reaction time cost occurs.

Our overall view of attention has shifted from a notion of limited capacity at particular stages to one of attention as a control process for the flow of information. The receipt of stimuli by a receptor passively activates much information stored in memory. But an active control process

can modulate the flow of information to memory, sometimes attenuating an input. In other circumstances the control process allows entry to all codes, but then selects only some codes or some information to be integrated with other information. The control process can preset itself for expected in-formation thereby improving overall efficiency, and when it selects some information, other conflicting information can be inhibited.

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63

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66

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Footnotes

[1] Recently Wardlaw and Kroll (1976) attempted to replicate the demonstration that a conditioned item in an unattended ear evokes a GSR change. They were unable to replicate the phenomenon. The reason for the discrepancy is unknown.

[2] Reference to Table 3 in LaBerge's paper reveals a data problem with one subject in this condition that could influence the interpretation of the results.

[3] Earlier another portion of Karlin and Kestenbaum's study was described in which first signal difficulty was varied. Here a portion of their data is selected dealing only with second signal difficulty.